Mobile Home Resident Evacuation Vulnerability and Emergency Medical Service Access during Tornado Events in the Southeast United States

Stephen Strader[1], Kevin Ash[2], Eric Wagner[1], and Chayla Sherrod[1]

[1] *Villanova University, Department of Geography and the Environment, Villanova, PA*
[2] *University of Florida, Department of Geography, Gainesville, FL*

Abstract

Tornado mortality is greatest in the Southeast United States (U.S.) due to an elevated tornado risk, a larger total developed land area, and a greater number of mobile and manufactured homes. The National Weather Service (NWS) and Federal Management Agency (FEMA) both recommend that mobile home residents evacuate to a nearby sturdier structure when tornado threats arise. However, previous research has indicated that less than 30% of mobile home residents evacuate their homes during tornado events despite their expressed willingness to flee. This study employs geospatial near and network analysis techniques from mobile and permanent homes to nearby potential sheltering locations to determine possible reasons for the less than ideal sheltering rates. Additionally, emergency medical service response times for mobile and permanent homes are also assessed using a network analysis methodology. Results indicate that the distances and travel times from mobile homes to shelters are significantly greater than that of permanent homes to shelters. The distances and travel times from first responder stations to mobile homes are also greater compared to those associated with permanent home residents. Findings from this research illustrate that in addition to mobile home residents being more physically and socioeconomically vulnerable to tornadoes, they are also disproportionally less served by potential sheltering locations and emergency services due to being located more commonly in rural areas, especially in southern Alabama. Outcomes from this study may also be utilized by emergency managers and policy makers to refine and implement new tornado preparedness and mitigation plans within southeastern U.S. communities.

Key words: Tornado, Vulnerability, Hazards, Evacuation, Mobile Home

Introduction and background

Just before midnight on 31 October 2018, the National Weather Service (**NWS**) in Shreveport, Louisiana issued a tornado warning for portions of Grant and LaSalle Parishes in Louisiana. This warning went out to the public through a variety of methods such as the Federal Communications Commission (**FCC**) and National Oceanic Atmospheric Administration (**NOAA**) Wireless Emergency Alert (**WEA**) system. The timeliness of this alert was especially crucial for a husband and wife located directly in the path of the oncoming warned tornado (NWS 2018). Once the couple received WEA text message alert via their cell phones, they fled their double-wide manufactured or mobile home (**MH**) for the permanent home (**PH**) of a nearby family member. After the tornado threat subsided, the couple returned to the area that their home once stood. The tornado had completely destroyed their home leaving a pile of rubble behind that contained all their life's possessions. The couple credited the WEA system and the act of evacuating their home with saving their lives. This anecdote highlights the importance of timely decision-making for protective action during tornado events. It also illustrates that when given enough time to take action, MH residents are able to evacuate their homes for perceived sturdier shelter.

The U.S. experiences 800-1,400 tornadoes per year with approximately 20% being rated category 2 or greater (EF2+) on the enhanced Fujita scale. A majority of U.S. tornadoes occur in the Central Plains region known colloquially as "Tornado Alley" (Brooks and Doswell 2002; Brooks et al. 2003; Ashley 2007; Gagan et al. 2010; Dixon et al. 2011; Dixon and Mercer 2012; Ashley and Strader 2016). However, most tornado-related deaths take place in the Southeast U.S. where a combination of societal and physical factors lead to elevated tornado mortality rates (Brooks et al. 2003; Ashley 2007; Ashley et al. 2008; Simmons and Sutter 2013; Ashley and Strader 2016; Strader and Ashley 2018). Factors such as a greater number of MHs, larger total developed land area, higher percentage of population living in poverty, more frequent significant tornadoes, and recurrent nighttime tornadoes in the Southeast lead to increased odds of tornado fatalities (Brooks et al. 2003; Ashley 2007; Dixon et al. 2011; Ashley and Strader 2016; Strader and Ashley 2018).

Previous research has investigated tornado risk and vulnerability in the Southeast using a variety of methodological approaches and data analysis techniques (Ashley 2007; Schmidlin et al. 2009; Sutter and Simmons 2010; Emrich and Cutter 2011; Simmons and Sutter 2013; Ashley and Strader 2016; Liu et al. 2019). Most notably, studies have concentrated their efforts on better understanding how societal vulnerability shapes disaster consequences (Cutter et al. 2003; Ashley et al. 2008; Schmidlin et al. 2009; Chaney and Weaver 2010; Simmons and Sutter 2013; Ash 2017; Strader and Ashley 2018). A common theme outlined in prior research examining societal vulnerability to tornadoes is the direct relationship between MHs and fatalities (Brooks and Doswell 2002; Ashley 2007; Schmidlin et al. 2009; Chaney and Weaver 2010; Sutter and Simmons 2010; Chaney et al. 2013). A majority of tornado deaths in the Southeast occur in MHs where people are 15-20 times more likely to be killed in a MH compared to a PH (i.e., single-family, duplex, apartment, etc.; Strader and Ashley 2018). In general, greater than 70% of all tornado fatalities are associated with housing (PH or MH) structures (Strader and Ashley 2018). Of these housing fatalities, at least half occur in MHs despite MHs comprising approximately 6% of the total U.S. housing stock (Census 2017). While elevated MH resident fatality rates can be attributed to MHs being more physically vulnerable to tornadic winds (i.e., typically complete destruction of a MH is expected for wind loads approximately 45% of those expected to destroy a PH; McDonald et al. 2006), MH residents are often more socioeconomically vulnerable to hazards compared to those living in PHs as well (Cutter et al. 2003; Fothergill and Peek 2014; Strader and Ashley 2018). This enhanced MH resident socioeconomic vulnerability has been illustrated in prior research to influence resident decision-making and protective actions taken during tornado events (Cutter et al. 2003; Schmidlin et al. 2009; Ash 2017).

Because MH residents are more vulnerable to tornadoes, the NWS and Federal Emergency Management Agency (**FEMA**) recommend that persons dwelling in MHs evacuate to a nearby sturdier building or shelter when tornado threats arise (NWS 2015; Ready.gov 2015). However, an estimated less than 20% of MH parks or communities in the Southeast provide storm shelters for their residents, compared to 75% or more of Central Plains MH parks (Schmidlin et al. 2001; Sutter and Poitras 2010).

In addition to the lack of MH resident sheltering options in the Southeast, studies assessing the shelter-seeking actions of MH residents have found that despite the recommendation of the NWS and FEMA, less than 30% of MH residents actually evacuate their homes during tornado events (Balluz et al. 2000; Schmidlin et al. 2009; Chaney and Weaver 2010; Chaney et al. 2013; Senkbeil et al. 2012; and Ash 2017). Yet, prior research has also suggested that given enough lead time, a majority of MH residents express willingness to evacuate or flee their MH for a perceived safer location such as the home of a relative or friend, place of worship, school, etc. (Ash 2015).

The concept of evacuation vulnerability is therefore useful to advance understanding of evacuation difficulties in the tornado context. Evacuation vulnerability refers to spatial and temporal constraints on safe and efficient evacuation behavior imposed by local and regional road network configurations and by access to pre-determined and/or *ad hoc* shelter locations (Cova and Church 1997; Kar and Hodgson 2008; Cova et al. 2013). For example, Cova and Church (1997) demonstrated how geographically isolated neighborhoods in Santa Barbara, California will consistently take longer to evacuate in response to rapid-onset hazards due to a limited number of escape routes coincident with higher population density. Kar and Hodgson (2008) demonstrated evacuation vulnerability in Florida by identifying areas with systematically reduced access to safe public hurricane shelters and potential alternative shelter locations (churches, schools, etc.). Similar work to identify places prone to greater evacuation vulnerability in association with tornadoes is needed to complement existing studies on tornado exposure and household sources of vulnerability (Durage et al. 2014).

In addition to the dynamic social, economic, and physical elements that influence MH vulnerability to tornadoes and shelter-seeking actions, rapid response is needed by emergency medical service (**EMS**) teams such as firefighters and other first responders (Brennan and Flint 2007; Ablah et al. 2013). Research has illustrated the importance of EMS response times in life threatening situations such as vehicular accidents (Gonzalez et al. 2009), shootings (Fielder et al. 1986), and hazard events (Curtis and Fagan 2013). Although MHs are more susceptible to being destroyed in tornado events, no study to date has examined resident evacuation vulnerability and EMS response times at the fine spatial scale (i.e., housing unit by housing unit) for a large geographic area (i.e., an entire state). While smaller, geographically focused studies allow for the assessment of local nuances and details pertaining to MH resident evacuation behavior and EMS response time, scaling this knowledge derived from community-driven studies to a large geographic study area provides a more holistic understanding of where to focus tornado hazard-MH resident mitigation efforts. The primary goal of this research is to highlight the potential issue of sheltering during tornado events using a newly created high spatial resolution dataset outlined in Strader and Ashley (2018). This manuscript ultimately serves as a baseline for future research that can investigate the additional physical, socioeconomic, and geospatial details of sheltering and emergency response during tornadoes.

Data and methods

This study seeks to better understand tornado event evacuation vulnerability and EMS response times for Alabama residents by utilizing fine-scale, geospatial data such as PH and MH locations and road network routes to conduct geospatial near and network analyses. Alabama is chosen for this study because it commonly experiences greater amounts of casualties and property damage compared to any other state in the southeastern U.S. (Ashley and Strader 2016; Ash 2017). First, tornado event likelihood and potential impacts on Alabama residents are assessed from 1950 to 2017. Tornado risk is defined as the probability of a tornado of a specific EF magnitude occurring in space and time. Following the methods of Ashley (2007), tornado event data were gathered from the Storm Prediction Center (**SPC**) SVRGIS database and fatality information for tornado events was extracted from a variety of resources such as the National Centers for Environmental Information (**NCEI**) storm event database and Grazulis tornado dataset (Grazulis 1993, 1997). Specifically, these resources provide a narrative of fatal tornado events that can be utilized to determine tornado fatality locations and circumstance of death (e.g., PH, MH, vehicle, outside). To observe regional differences in Alabama tornado risk and mortality, spatial analysis techniques such as gridded frequency and kernel density estimation (**KDE**) methods were applied to the tornado event and fatality data. As a means to provide a measure of tornado event potential within Alabama, NWS-issued tornado watches and warnings for Alabama were also examined from 2007 to 2017 using spatial analysis techniques. The tornado watch and warning data were compiled using the Iowa Environment Mesonet (**IEM**) geospatial watch and warning archive. Because storm-based tornado warnings did not become operationally standard until 2007, only the years of 2007 to 2017 were considered for analyses (Harrison and Karstens 2017).

Although MH count estimates can be determined at the Census block group geographic level, precise (latitude, longitude coordinates) locations of PHs and MHs within the census block groups are not available via American Community Survey (**ACS**) data. Thus, we employed land parcel data that provides high spatial resolution locations of PHs and MHs in Alabama (Strader and Ashley 2018). While the parcel data capture a majority of precise housing locations in Alabama, supplemental data collection techniques were also utilized to either correct or determine missing home locations within the parcel dataset. Specifically, National Agriculture Imagery Program (**NAIP**) and the ESRI Community Maps Program imagery at 1-meter resolution were utilized in conjunction with a “head’s up” digitization methodology to correct or find missing MH locations. Google Map’s Street View and common MH dimensions (i.e., 5.5-m by 27-m for single-wide) were used to confirm if a structure was a MH and should be added to the dataset. These data collection steps and methodology allowed for a highly accurate and precise collection of MH locations for Alabama. Specific data creation processes and steps are outlined in Strader and Ashley (2018).

The total number of housing units (**HU**s) and land use density classifications were derived from the spatially explicit regional growth model (**SERGoM**; Theobald 2005). The SERGoM consists of fine-scale (100-m) gridded estimates of the number of HU per hectare (ha) and classifies HU density as either rural (< 0.062 HU per ha), exurban (0.062-1.236 HU per ha), suburban (1.237-9.884 HU per ha), or urban (> 9.884 HU per ha). Together with the PH and MH point data, the SERGoM land use density estimates were utilized within this study to determine whether a home was located in rural, exurban, suburban, or urban land use.

Community-designated tornado shelter (**CDTS**) locations throughout Alabama were also digitized into a GIS. Common types of CDTS were FEMA community tornado shelters (FEMA 2015), schools, places of worship (e.g., churches), or municipal buildings. Because of the wide variety of CDTS types, a sheltering location was deemed as a CDTS if the county or township associated with the shelter facility publicly indicated on a website or by telephone that residents in the area could evacuate their home and flee to the shelter prior to a tornado event. Thus, CDTSs do not necessarily have to meet any wind load or structural criteria to be considered. Because there is no publicly available data repository containing the locations of all CDTSs in Alabama, geospatial data were generated from a variety of resources such as county emergency management websites, local news station press releases, and/or telephone calls made to the local county emergency manager to obtain CDTS addresses or coordinates. Similar to the head's up digitizing process used to generate MH locations, CDTS locations were digitized into a GIS using either an address, latitude-longitude coordinates, or other identifiable location information associated with the shelter. In addition to CDTS locations, critical infrastructure facility (i.e., EMS stations and hospitals) locations were downloaded from the Homeland Infrastructure Foundation-Level Data (**HIFLD**). EMS stations are made up of a combination of ambulance services (public or privately owned), fire stations (municipality or volunteer), and other first responder services. The combination of MH, PH, CDTS, and EMS locations allow for the assessment of Alabama resident evacuation potential to shelters and EMS response times to homes before and after tornado events.

For this particular study, a combination of near and network analysis techniques were employed to determine distance and travel time from PH and MH to the nearest potential tornado shelter (i.e., place of worship, school, or CDTS). Near and network analyses were also conducted using the housing location points and EMS stations or hospitals to provide a baseline estimate of emergency medical service travel times following a tornado event. Near analyses provide a measurement of the shortest distances from geographic point to point without taking any obstacles (e.g., roads, buildings, trees, fences, etc.) into account. This type of distance analysis is often referred to measuring the distance between two points "as the crow flies". Near distance between two objects is most accurate when two locations are close and the likely path of travel from location to location is a straight line over relatively flat terrain. For example, a MH resident may evacuate on foot to a nearby shelter such as a neighbor's PH if the distance between the MH and PH is less than 0.5 km. Near analysis techniques are specifically used in this study to measure the distance between homes where residents might flee their housing structure on foot to a nearby family member's or friend's PH.

Network analysis within a geographic information system (**GIS**) is comprised of connected vertices and edges that allow for the assessment of connectivity, adjacency, and incidence of geographic points (Curtin 2007). In general, network analyses allow for the estimation of distances and travel times for persons who are traveling by vehicle. The research presented herein employs the Environmental Systems Research Institute (ESRI) network analyst toolset made available in the ArcGIS Professional edition. Specifically, the closest route tool within the network analyst suite was employed in conjunction with Alabama's road network so that objects (i.e., resident personal vehicles and emergency vehicles) can travel through the network from place to place. Comprehensive and highly detailed Alabama road data was compiled from 2013 Tom Tom data made available through ESRI. The road network was extended outside of the Alabama Stateline to prevent any edge effects within the network analysis travel time and distance estimations (Gil 2016). Travel times and distance calculations are measured such that objects traveling through the network do so at the posted speed limit and encounter no barriers (i.e., downed trees, road closures, accidents, etc.). While calculating precise response times is incredibly nuanced and complex (Cutter 2003; Chen et al. 2005; Larson et al. 2006), by extending the road network outside of state lines and assuming travel speeds occur at posted speed limits, we were able to create estimates of first responder travel times and distances to homes.

We utilize network and near analyses to generate lower bound estimates of resident evacuation clearance and emergency response travel times, while noting that our analyses do not represent comprehensive estimates of evacuation clearance times, which require consideration of several additional variables. For example, Lindell et al. (2018) provide a framework wherein total evacuation clearance time is calculated as (Equation 1):

$$t_T = f(t_d, t_w, t_p, t_e) \qquad (1)$$

where t_T is a household's total clearance time, t_d is the authorities' decision time, t_w is the household's warning receipt time, t_p is the household's evacuation preparation time, and t_e is the household's evacuation travel time. However, because we do not attempt to estimate t_d, t_w, and t_p in the calculation of resident evacuation and first responder travel times (i.e., $t_d = 0$, $t_w = 0$, and $t_p = 0$), this study only produces *lower bound* estimates of resident evacuation clearance and first responder travel times. Thus, for this particular study we equate travel times for residents and emergency responders to lower bound clearance and response times. Additionally, network and near analysis results in this study also ignore the potential problem of queuing on the evacuation routes when demand (e.g., the number of evacuating vehicles) exceeds supply (e.g., the capacity of the evacuation route system in terms of network geometry and link capacity) because it is unlikely for queuing to arise in more rural areas of Alabama where a majority (80%) of MHs reside. Nevertheless, the lower bound estimates of resident clearance and response times in this study provide an baseline assessment of the tornado-MH resident evacuation problem in the Southeast U.S.

Results

Tornado climatology and risk

From 1950 to 2017, 1,882 tornadoes occurred in Alabama with 610 being rated significant EF2+ and 45 of them as violent EF4+. Northern Alabama has experienced the greatest frequency of tornadoes since 1950, with the highest concentration (>25 km^{-2}) of tornadoes traversing the corridor between the cities of Birmingham and Huntsville (**Figure 1**). Although the southwestern counties of Mobile and Baldwin are located in a region where tornado density is relatively lower than north-central Alabama, tornado occurrence is also elevated (>1 yr^{-1}) in these counties. Unlike north-central Alabama where there is a larger percentage of tornadoes that are significant EF2+, many of the tornadoes that have occurred in southwestern Alabama were rated EF0 and EF1 magnitude. The elevated EF0 and EF1 tornado occurrence in these counties is likely attributed to the greater frequency of tornadoes that are produced by non-supercell thunderstorms. For example, coastal thunderstorms in this region often produce waterspouts that move on land and become tornadoes (Brooks et al 2003; Giaiotti et al. 2007). The greater number of EF0 and EF1 tornadoes in Mobile and Baldwin counties may also be attributed to tornadoes spawned by tropical storms making landfall in the region (Edwards 2012). Although population density may be at least partly responsible for the greater tornado frequencies experienced in northern Alabama compared to southeastern portions of the state (e.g., Anderson et al. 2007), Jefferson and Cullman counties have experienced the greatest number of tornadoes since 1950 with 91 and 76 tornadoes, respectively.

Over the last 67 years, significant tornadoes have resulted in 623 fatalities in Alabama. Despite significant and violent tornadoes making up 32% and 2% of all Alabama tornadoes, they are responsible for 98% and 77% of all fatalities. The 27 April 2011 outbreak single-handedly produced nearly 200 tornadoes, 300 fatalities, 2,700 injuries, and an estimated 11 billion USD in damage across Alabama (NOAA 2011). The EF4 Tuscaloosa-to-Birmingham tornado alone was responsible for 65 fatalities on 27 April 2011 (Knupp et al. 2013). Again due to the lack of significant or violent tornadoes occurring in Mobile and Baldwin counties, a minimum in Alabama tornado fatalities occurs in this region. Jefferson County has witnessed the greatest number of fatalities since 1950 with 105 followed by Tuscaloosa (63) and Madison (43) counties. Fatality rates are greatest in northern Alabama (**Figure 1**) where there are approximately 51 fatalities per 100 tornadoes. This higher tornado fatality rate is attributed to northern

Alabama comprising a higher tornado risk and greater overall number of people exposed to tornadoes compared to southern Alabama.

A majority of tornado watches since 2007 have occurred in southwestern Alabama with Baldwin County being under a tornado watch approximately 15 times per year (**Figure 1**). Tornado watch frequency decreases from the southwest to northeastern Alabama with Jackson County experiencing 67 total tornado watches (6 yr^{-1} mean) since 2007. The spatial pattern of tornado warning counts is much different than that of tornado watches. While a majority of tornado watches have occurred in southwestern Alabama, north-central and southwestern portions of the state have experienced a comparable number of tornado warnings. For example, both Tuscaloosa and Baldwin counties have witnessed approximately 15 tornado warnings per year despite their differences in geographic location. The discrepancy between tornado watch and warning patterns can be attributed to large tornado outbreaks (e.g., 27 April 2011) where a high number of tornado warnings compared to few tornado watches are often issued for these events. However, these factors only account for the climatological risk element in Southeast tornado disasters.

Housing units, permanent homes, mobile homes, and land use

Prior research has illustrated the importance of understanding exposure elements of vulnerability as it pertains to tornado disaster potential (Ashley et al. 2014; Ashley and Strader 2016; Strader and Ashley 2018). For instance, Southeast tornado disaster potential is controlled by both societal and physical factors that lead to increased tornado mortality rates (Brooks et al. 2003; Ashley 2007; Ashley et al. 2008; Simmons and Sutter 2013; Ashley and Strader 2016; Strader and Ashley 2018). Of these factors, HU and MH counts and density have been shown to be strongly tied to increased tornado impact potential and fatalities (Ashley and Strader 2016; Strader and Ashley 2018). Together, these findings point to the importance of understanding land use and development density as it related to HUs, PHs, and MHs in the Southeast.

There are approximately 1.8 million total HU located in Alabama with a majority of them being associated with cities such as Birmingham, Huntsville, Mobile, Montgomery, and Tuscaloosa. (**Figure 2; Table 1**). An estimated 1.6 million or 89% of HUs in Alabama are considered PH structures (i.e., single-family homes, apartments, duplexes, etc.) with the remaining being categorized as MHs. Although only 11% of Alabama HUs are MHs, this percentage is approximately six percentage points greater than the U.S. state mean where only 5% of the U.S. housing stock is made up of MHs. However, MHs, PHs, and all HUs are not evenly distributed across the Alabama landscape. Despite nearly 70% of Alabama developed land area being classified as rural land use, a majority (80%) of Alabama HUs are concentrated in exurban and suburban development density. Conversely, only 13% (234,890 HUs) of all Alabama homes are in rural areas. Although urban land use comprises the least amount (0.23%) of total developable land area in Alabama, an estimated 123,079 HUs or 7.0% of HUs are located in urban settings.

Splitting the state into northern and southern parts along the East Gulf Coastal Plain reveals housing differences between the two state regions. The state was split up into these two parts because this is the region of the state where there is a transition from relatively higher relief areas such as highlands, plateaus, hills and valleys, etc. found in the northern portion of the state and lower relief coastal plains regions in southern Alabama (**Figure 2**; dotted black line). Additionally, this is the region where there is a stark transition in socioeconomic and demographic factors (e.g., race, income) commonly associated with northern and southern regions of Alabama (Strader and Ashley 2018). These latter factors are tied directly to demographics and populations with elevated tornado mortality and evacuation potential (Ash 2017; Strader and Ashley 2018). A majority of HUs are located in exurban land use in both state regions with exurban HUs in the northern portion of the state comprising 46% of all northern Alabama homes. In southern Alabama, 40.8% of all HUs reside in exurban regions despite 80% of southern Alabama land use density being categorized as rural. While the percentage of HUs in urban areas is nearly identical between northern and southern Alabama, the total number of HUs in southern Alabama is approximately 5% greater in rural locations.

A majority of PHs and MHs in Alabama are located in exurban land use. However, PHs are far more likely than MHs to be in urban and suburban land use throughout the entire state. For instance, 45% of all PHs in Alabama are located in urban and suburban areas compared to only 19% of MHs (**Table 1**). Additionally, the percentage of MHs in rural areas is nearly double that of PHs throughout the state and only 1.9% of all MHs are located in urban regions compared to 7.7% of PHs. Comparing HUs, PHs, and MHs counts and land use throughout Alabama, MH land use is shifted towards lower development density. For example, nearly 82% of MHs are located in exurban and rural land use compared to only 55% and 58% of PHs. Together, these results illustrate that MHs throughout Alabama are more commonly located in lower density development outside of the primary urban and suburban city cores (Strader et al. 2018).

Separating PHs and MHs into northern and southern portions of the state reveals regional differences among each housing type as it relates to land use density. The difference between MH and PH counts in urban and suburban land use is much larger in the southern region of the state compared to northern Alabama. The percentages of rural MHs in both northern (20.0%) and southern (27.6%) portions of the state are much greater compared to those associated with PHs in rural regions (10.9% northern; 15.1% southern). Although a greater number of MHs are in northern Alabama, the percentage of MHs in rural land use is greater in southern Alabama. The elevated numbers of MHs in rural and exurban land use compared to PHs can, in part, be explained by zoning laws and development practices in larger cities (e.g., Birmingham, Huntsville, Montgomery, Tuscaloosa) where it is common that MHs are not allowed to be located within city limits (Flippen 1974; Berry 1985; Aman and Yarnal 2010). While southern Alabama PHs and MHs are both more frequently located in exurban and rural areas compared to northern Alabama, the difference between MH land use and PH land use in southern Alabama is evident. Specifically, MHs are 1.5 times or 50% more likely to be in rural or exurban land use in southern

Alabama compared to PHs. Overall, although MHs are more commonly in lower density regions throughout the state, the difference between the percentages of MHs and PHs in rural and exurban areas is far greater in southern Alabama.

Potential tornado sheltering and first responder locations

There are a total of 4,136 places of worship, schools, and CDTS in Alabama with 2,725 being located in the northern and 1,411 in the southern portion of the state (**Figure 3; Table 2**). Normalizing these potential shelter locations by the population, there are approximately 0.85 tornado shelters per 1,000 people throughout all of Alabama. Schools make up a majority 48.5% (0.41 per 1,000 people) of potential shelters in Alabama followed by places of worship with 38.9% (0.33 per 1,000 people). There are only 522 CDTS (0.11 per 1,000 people) throughout Alabama comprising just 12.6% of all potential shelters in the state. A majority (90%) of CDTS are located in northern Alabama, suggesting that communities in northern Alabama have placed a greater emphasis on providing tornado sheltering options for residents.

Although northern Alabama contains a greater number of potential tornado shelters compared to southern portions of the state, again normalizing the total number of available shelters by the regional population also reveals the importance of considering land use and development patterns rather than solely the total population in each region. Specifically, there are 0.94 potential tornado shelters per 1,000 people in southern Alabama compared to 0.81 in northern portions of the state. Although these statistics conversely suggest that there are in fact more sheltering options for southern Alabama residents compared to northern Alabama, this can be misleading as the distribution of the population or shelters across each state region is not taken into account (i.e., development density in southern Alabama is much more rural compared to northern Alabama). Thus, to properly assess resident access to potential tornado shelters *both* the total count and land use density relative to their location for population and potential tornado shelters must be considered.

A majority (44.1%) of potential sheltering locations are in exurban density throughout Alabama (**Table 3**). This finding was expected given the vast majority of Alabama residents are located in these same exurban areas. However, only 13.5% of all potential shelters are in rural land use indicating that residents in rural Alabama areas have fewer tornado sheltering options compared to those living in greater development density. Because southern Alabama is more rural than northern portions of the state and MHs and PHs are more likely to be located rural areas in southern Alabama, residents in these locations have the fewest number of tornado sheltering options compared to any other group in the state.

While tornado shelters and their locations are important prior to and during tornado events, first responder locations (EMS station and hospital) are crucial for saving lives following a casualty producing tornado. There are a total of 1,229 (0.25 per 1,000 people) first responder locations in Alabama with 68.4% of them located in the northern half of the state (**Figure 3; Table 3**). In addition to a majority 89.3% of first responder locations being EMS stations, roughly 51.4% of them are in exurban land use. Conversely, 20.0% of EMS stations are in rural land use compared to only 6.1% of hospitals. The increased percentages of EMS stations in rural land use are a result of elevated numbers of volunteer fire-rescue stations often located in rural areas (Cowlishaw et al. 2008). The combined effect of a fewer number of tornado shelters and EMS stations in southern Alabama as well as a more rural land use for populations, shelters, and EMS stations indicates that residents living in the southern region of the state have fewer sheltering options and are less served by first responders compared to northern Alabamians. Yet, the most underserved residents in Alabama are MH residents given they are more likely to be located in rural/exurban lands, far more likely to evacuate their home prior to or during a tornado event, and subject to elevated casualty rates due to their more physically vulnerable homes.

Tornado shelter near analyses

While the locations and spatial pattern of homes, shelters, and first responder stations provides a broad measure of resident evacuation and emergency service potential, geospatial near analyses examine the evacuation and sheltering potential on a house by house basis for MH and PH residents in Alabama.

Again, near analysis is a basic spatial analysis process that determines the closest point (e.g., PHs) for a set of points (e.g., MHs) and calculates the shortest the straight-line distance following the curvature of the earth's surface from point to point. Prior research has utilized near analyses to assess topics such as sight distance of highways (Castro et al. 2011), wind farm site selection (Van Haaren and Fthenakis 2011), etc. The near distance analyses presented in this study highlight resident evacuation potential if they choose to flee their homes for perceived sturdier shelter on foot (i.e., MH to neighboring PH).

In northern Alabama, the mean (median) distance between MHs and the closest PH is 2.2 (3.2) times greater than the mean distance from PHs to the closest PH (**Table 4**). The variability (coefficient of variation) measures for northern and southern Alabama indicate that there is less variation in the southern Alabama distances from MHs to PHs. This suggests that MHs are more uniformly spread across the landscape and less likely to be clustered near PHs. The same near analysis distance patterns hold true for southern Alabama where the mean and median near distances from MHs to the closest PH are all greater than those associated with PHs to PHs. Comparing the northern and southern Alabama, mean near distances from MHs to PHs are slightly greater in southern Alabama compared to northern portions of the state. This finding suggests that MHs are on average located farther from PHs compared to northern Alabama. However, median near distances from MHs to PHs in southern Alabama are slightly lower than those associated with the northern half of the state. These MH to PH measures of central tendency results suggest that there are a greater number of highly isolated MHs in South Alabama compared to North Alabama. In general, the near MH and PH analysis results indicate that Alabama MH residents may have a longer distance to flee during a tornado event if their shelter of choice is a nearby PH, regardless of whether they reside in northern or southern regions of the state.

Tornado shelter network analyses: State patterns

Network analysis techniques were used to conduct distance and time measurements for HUs (PHs and MHs) to potential tornado shelters using Alabama roads, places of worship, schools, and CDTS. Network analyses measure the distance and travel time from location to location along an integrated network such as roads or trails. Prior research has utilized network analyses to examine a variety of topics such as urban access to green spaces for different ethnic groups (Comber et al. 2008), water flow and transport (Djokic et al. 1993), etc. The network time and distance analyses in this particular study highlight resident evacuation potential if they choose to flee their homes for a public tornado shelter by means of an automobile.

Overall, the greatest travel times (> 30-min) and distances (> 24-km) from all Alabama HUs to a potential tornado shelter are associated with CDTS. This result is likely attributed to the fewer number of CDTS available throughout the state, especially in the southern region. The average (mean) time and distance from a HU to a shelter of any type in Alabama is 13.7-min and 9.5-km. The median time and distance for all Alabama HUs and shelters are slightly less than the mean at 11.4-min and 7.7-km, highlighting the effect isolated, rural homes have on travel times and distances to tornado shelters throughout the state. This finding is vastly important given nearly 80% of Alabama MHs are located in rural and exurban land use (Strader and Ashley 2018).

Tornado shelter network analyses: Regional patterns

The times and distances for all HUs (PHs and MHs) to the nearest place of worship, school, or CDTS are 6.5-min and 5.7-km greater on average (mean) in southern Alabama (**Table 5**). Median travel times and distances from all HUs to the closest shelter are comparable to the mean. These results suggest that those residing in southern Alabama have longer travel times and distances to the closest potential tornado shelter, regardless of their housing type. While this finding can be attributed to the greater overall percentage of HUs that are located in rural and exurban land use in southern Alabama (**Table 5**), it also indicates that evacuation prior to or during tornado events may be a less viable option for southern Alabama PH and MH residents. Lastly, the variability in southern Alabama HU travel times and distances is also 3.6-min and 3.7-km larger than in northern Alabama, suggesting that many southern Alabama residents have elevated travel times and distances even compared to their rural neighbors.

Tornado shelter network analyses: PH and MH patterns

In addition to greater southern Alabama travel times and distances to shelters, the travel times and distances from MHs to shelters are greater than that of PHs throughout all of Alabama. For instance, the mean travel time and distance for Alabama MHs to the closest potential tornado shelter (place of worship, school, or CDTS) is 3.0-min and 2.0-km greater than PH travel times and distances to shelters. The largest discrepancy between PH and MH travel times and distances are associated with MHs and places of worship. In this network analysis scenario MH residents have to travel 4.5-min longer and 3.5-km farther compared to PHs to reach the closest place of worship. Of all potential shelter locations the travel times and distances from PHs and MHs are most similar with CDTS. This result is expected given CDTS are built in specific locations based on MH locations and community needs (Whalen et al. 2004; FEMA 2015).

Tornado shelter network analyses: PH, MH, and regional patterns

Taking both the housing type and regional differences into account, the travel times and distances for MH residents in southern Alabama to potential sheltering locations is greatest compared to all other regions and housing types. Specifically, MH resident travel times and distances are 2.9-min longer and 2.0-km farther than in northern Alabama and 3.0-min and 2.1-km greater in southern Alabama compared to the PHs in these same regions. The greatest difference between PH and MH travel times and distances for either northern or southern Alabama is associated with MHs and places of worship in northern Alabama. MH travel times and distances are 5.4-min and 3.7-km greater for MHs in northern Alabama compared to PH in the same region. This result is indicative of northern Alabama's land use patterns where larger percentages of places of worship and PHs are located in urban and suburban regions. Together, the combination of elevated numbers of places of worship and PHs in northern Alabama urban and suburban areas results in shorter travel times and distances compared to MHs. However, PH and MH travel times and distances to CDTS in northern Alabama are nearly identical to each other, again highlighting the systematic selection process that goes into designating or building a CDTS for a particular community. Notably, the mean and median travel times by automobile to the nearest CDTS in southern Alabama of approximately 29 to 33 minutes far exceed the national tornado warning lead time of about 13 minutes (Brotzge et al. 2013). This means that residents in southern Alabama would be required in many instances to evacuate well before the issuance of a tornado warning in order to arrive safely at the nearest CDTS.

First responder network analyses

Travel times and distances from all Alabama HUs to hospitals are greater than that of HUs to EMS stations (**Table 6**). This results is due to a larger number of EMS stations throughout Alabama. For example, most counties have many EMS stations (e.g., fire stations) compared to one or a few private or public hospitals. The average (mean) travel time and distance from HUs to EMS stations are 8.9-min and 5.6-km, respectively throughout the state. However, the mean Alabama travel time and distance from HUs to hospitals are 21.8-min and 15.3-km. These results equate to 12.9-min and a 9.8-km difference in travel times and distances for HUs in Alabama. The median and variability in travel times and distances from all Alabama HUs to hospitals are also larger compared to that of EMS stations across Alabama, again indicating the effect of a fewer total number of hospitals compared to EMS stations.

Travel times and distances from first responder locations to PHs and MHs are slightly greater in southern Alabama compared to northern portions of the state. This is likely due to the more rural land use patterns in southern Alabama. The differences between travel times from EMS stations to HUs in northern Alabama are less than those associated with EMS stations to HUs in southern Alabama. Specifically, EMS station response to HUs are 1.5-min longer and 1.2-km farther in southern Alabama. Comparing PH and MH travel times and distances to EMS and hospitals for the entire state of Alabama reveals that the times and distances from the closest EMS station to MHs are 3.3-min and 2.2-km greater on average (mean) compared to PHs throughout Alabama. Similarly, mean hospital to MH travel time (7.5-min) and distance (5.8-km) are much larger than PHs as well. This result is attributed to the larger percentage of MHs in rural and exurban land, as well as the lack of MHs in urban and suburban regions where EMS and hospitals are more common.

Examining both regional and housing type differences in travel times and distances from first responder locations and homes provides an assessment of where Alabama residents are least served following a tornado event. The greatest travel time and distance for all first responder network analyses are associated with hospitals to MHs in southern Alabama where the mean travel time is 25.8-min and 18.2-km. However, the travel time from hospitals to MH in northern Alabama are similar with mean travel times of 25.2-min and 18.2-km. Together, this result indicates that whether or not you reside in southern or northern Alabama, if you live in a MH your access to services is reduced in comparison to PHs in the same region. For EMS to MH and PHs in either southern or northern Alabama, the greatest travel times and distances are again related to MHs in southern Alabama where it takes an average (mean) travel time of 11.4-min over 7.4-km. The largest difference between MHs and PHs occurs with the travel time and distance from hospitals to MHs in northern Alabama. For instance, the mean travel time and distance from the closest hospital to MH in northern is nearly 8.0-min longer or 6.0-km farther. Again, this is due to MHs being less common in suburban and exurban lands where PHs and hospitals are more commonly located.

Discussion and conclusions

This study employed high resolution geospatial analysis techniques to assess Alabama tornado risk, tornado evacuation vulnerability in terms of sheltering options, and first responder response times and distances to homes that could potentially be affected during a tornado event. We have provided substantial evidence illustrating that the MH resident populations in Alabama have fewer tornado sheltering options and are disproportionately farther from first responder services. The combination of elevated Alabama significant tornado risk and greater number of less wind resistant housing stock (i.e., MHs) leads to increased physical vulnerability for many residents living in the state. This study also demonstrates that residents with heightened physical and social vulnerability to tornadoes often live in lower development densities (i.e., rural and exurban land use) that further exacerbates their evacuation vulnerability.

While previous studies have highlighted similar patterns in hazard risk and vulnerability, this study went a step further and examined housing evacuation vulnerability using lower bound clearance time estimates for a range of potential sheltering options, as well as lower bound response time estimates for emergency medical service personnel that would provide services for these vulnerable populations. Our results highlight the disparity between PH and MH tornado sheltering options and emergency medical service lower bound response time estimates in northern and southern Alabama. Although most Alabamians reside in northern portions of the state and a majority of community tornado shelters are located in northern Alabama, southern Alabama residents have disproportionately fewer tornado sheltering options. In addition, MH residents also have fewer tornado shelter options available, especially those residing in rural southern Alabama. Together, these findings highlight an important disparity between those physically and socioeconomically more vulnerable residents that are in need of publicly accessible tornado sheltering options versus the number of shelter options that are available. We did not consider, however, privately owned tornado shelters (underground shelters or safe rooms) in our near and network analyses. Research building upon this study in the future should, if possible, collect data on the prevalence and geographic distribution of these private shelters across Alabama and other tornado prone southeastern states, as such shelters may be important destinations for local tornado evacuation and have been shown to be cost-effective for MHs in other tornado prone areas of the U.S. (Simmons and Sutter 2006).

To date, no study has investigated tornado evacuation vulnerability, sheltering options, and emergency medical service travel times using near and network analyses on a unit by unit basis over a large geographic area (i.e., Alabama). The findings presented in this study suggest that MH occupants systematically have greater estimated travel times to community designated tornado shelters and emergency medical services—especially hospitals. Therefore, to improve safety outcomes associated with tornado events in Alabama, MH residents need better guidance and options for sheltering. Research to determine which places of worship, schools, or other public buildings would be suitable shelters could add more options for residents wishing to seek shelter away from their MH, especially in exurban and rural locations. There is also a need to explore how potential routes to sheltering locations could interact with tornadic storm directions and speeds of forward motion to dramatically reduce time available to safely travel to a shelter. Finally, the need to find better shelter and travel in the face of an impending storm could be mitigated in the long-term by improvements in siting, anchoring, and building quality of individual MHs, and through retrofitting of existing MHs so that they can better withstand tornadic winds and provide more adequate shelter. As such, emergency managers and elected officials should only consider community tornado shelters as a component to larger tornado mitigation and resilience-building plans across local, state, and federal levels.

In this study, we included places of worship and schools as possible sheltering locations for MH occupants based on findings of preferred tornado sheltering locations as previously identified by this sub-population in the southeastern U.S. (Ash 2015). However, many places of worship and schools may not represent significantly safer options than being in a MH, based on past events in which numerous fatalities occurred in these types of structures (Schmidlin and King 1995; Masoomi and van de Lindt 2016). Specifically, fatality rates in places of worship and schools and the structural vulnerability of these facilities depends on the structural integrity of the building and whether people are sheltering in these facilities' large-span buildings, such as auditoriums and gymnasiums, or in their interior hallways of smaller-span structures such as classroom buildings. Furthermore, even if a nearby place of worship or school might structurally be sound enough to serve as a shelter, the ability to access and enter the building could be restricted, and once inside the designated sheltering areas may be at capacity. Thus, future work should focus on issues of potential shelter suitability, including structural integrity as well as building accessibility and capacity.

The near and network analyses performed in this study serve as *baseline estimates* of evacuation vulnerability based on travel times for evacuation to shelters and for proximity to emergency medical services. In the near analyses, our models did not account for variability in travel times on foot that might arise from local weather conditions, topography, land cover types, or individual mobility differences (Wood et al. 2018). Our network analyses did not consider uncertainties in travel time estimates due to the day of the week, time of day, traffic congestion, road conditions, construction delays, unexpected barriers (e.g., accidents, downed trees, flooding), or individual driving preferences or differences (see Lindell et al. 2018 for a comprehensive review of factors relevant for evacuation time estimates). We also assumed that the nearest potential shelter is congruent with the most likely sheltering destination of each household, which will not necessarily be true as people may travel farther due to personal preferences, direction of tornado movement, or other reasons. With respect to critical time elements in warnings and emergency medical response, we did not account for factors such as time lost during communication of warnings or in requests for medical assistance, or mobilization times of households prior to departing for a shelter or of emergency medical personnel prior to departing to render aid. Overall, the evacuation time variables omitted (t_d, t_w, and t_p) from the study's analyses do not affect the differences between regions or housing types when assuming that there are no differences between regions or resident warning reception and evacuation preparation. Thus, our baseline distance and travel time estimates served their purposes for comparisons of evacuation vulnerability across regions of Alabama and between housing types.

Future research should also focus on the human component of resident evacuation decisions, especially for MH residents. For instance, many other factors besides time and distance to the closest tornado shelter influence decision making at the individual level prior to a tornado event. This complexity also holds true for emergency response after tornado events (Auf der Heide 2006). Specifically, future work should incorporate tornado warning and lead times into analyses. Given the omission of evacuation time variables such as authorities' warning decision time, household's warning receipt time, and a household's evacuation preparation time, residents may actually have a less time to take action than our results indicate (Cova et al. 2017; Lindell et al. 2018). Evacuation is a complex process with many variables and a more comprehensive assessment of resident evacuation clearance time and associated variables should be considered once future work takes warning lead time into account.

While a few researchers have started to investigate decision making factors associated with resident evacuation during tornado events (see Casteel 2018; Drost et al. 2016; Durage et al. 2015; Walters et al. 2019), results from this study should be combined with future work aimed at the assessment of the relationships among housing types, land use density, tornado shelters, and resident actions. Incorporation of members of Integrated Warning Teams (**IWT**) (e.g., NWS forecasters, emergency managers, media, researchers) as well as urban planners, structural engineers, economists, and housing industry experts, will be critical for consideration of all relevant factors so that strong conclusions may be drawn and implemented into policies to improve communication, address existing vulnerabilities, and increase community resilience, reducing the overall scope of tornado impacts.

Acknowledgements

Funding for this research was provided by the NOAA VORTEX-SE project (NA17OAR4590191). We also thank Dr. Walker Ashley (NIU) for sharing his tornado fatality data. Lastly, we thank the anonymous reviewers for their thoughtful comments and suggestions.

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Tables

Table 1. Northern, southern, and all Alabama mobile homes (MH), permanent homes (PH), and all homes (housing unit; HU) counts and percentage of homes within that housing type category by rural (< 0.062 HU per ha), exurban (0.062-1.236 HU per ha), suburban (1.237-9.884 HU per ha), urban (> 9.884 HU per ha) land use class.

		MH Count	**% of Total MH**	**PH Count**	**% of Total PH**	**Total HU Count**	**% of Total HU**	**% Region Land Use**
North AL	Rural	25,504	20.0	114,956	10.9	140,460	11.9	55.7
	Exurban	78,041	61.1	470,920	44.6	548,961	46.4	41.2
	Suburban	21,829	17.1	390,039	36.9	411,868	34.8	2.8
	Urban	2,359	1.8	80,494	7.6	82,853	7.0	0.3
South AL	Rural	19,640	27.6	74,790	15.1	94,430	16.7	79.9
	Exurban	38,359	54.0	192,285	38.9	230,644	40.8	18.8
	Suburban	11,711	16.5	187,995	38.1	199,706	35.3	1.1
	Urban	1,388	2.0	38,838	7.9	40,226	7.1	0.1
All AL	Rural	45,144	22.7	189,746	12.2	234,890	13.4	68.1
	Exurban	116,400	58.5	663,205	42.8	779,605	44.6	29.8
	Suburban	33,540	16.9	578,034	37.3	611,574	35.0	1.9
	Urban	3,747	1.9	119,332	7.7	123,079	7.0	0.23

Table 2. Potential tornado shelter and first responder counts and density for northern, southern, and all of Alabama.

	Count			**Facility per km^2**		
	Northern Alabama	**Southern Alabama**	**All Alabama**	**Northern Alabama**	**Southern Alabama**	**All Alabama**
Places of Worship	928	680	1,608	0.014	0.010	0.012
Schools	1,330	676	2,006	0.020	0.010	0.015
CDTS	467	55	522	0.007	0.001	0.004
Total	2,725	1,411	4,136	0.041	0.021	0.031
EMS	760	338	1,098	0.011	0.005	0.008
Hospitals	81	50	131	0.001	0.001	0.001
Total	841	388	1,229	0.013	0.006	0.009

Table 3. Potential tornado shelter and first responder counts per rural (< 0.062 HU per ha), exurban (0.062-1.236 HU per ha), suburban (1.237-9.884 HU per ha), urban (> 9.884 HU per ha) land use classifications.

	Count per Land Use Category			
	Rural	**Exurban**	**Suburban**	**Urban**
Places of Worship	262	542	766	38
Schools	186	934	862	24
CDTS	110	346	65	1
Total	558	1822	1693	63
EMS	220	584	286	8
Hospitals	8	48	75	0
Total	228	632	361	8

Table 4. Mobile home (MH) and permanent home (PH) near analysis results for

northern and southern regions of Alabama. Mean, median, standard deviation, and coefficient of variation (CoV) for near distances (m) are given for each regional and housing type scenario.

			Distance (m)			
Scenario (Facility)	**Region**	**Housing Type (Incident)**	**Mean**	**Median**	**Std. Dev.**	**CoV**
Permanent Home (PH)	North	PH	64.6	34.8	87.8	1.4
		MH	145.3	110.3	125.8	0.9
	South	PH	72.0	31.7	130.7	1.8
		MH	147.3	103.2	157.9	1.1

Table 5. Mobile (MH) and permanent home (PH) network analysis results for potential tornado shelters in northern and southern Alabama. Mean, median, standard deviation, and coefficient of variation (CoV) for

travel time (min) and distance (km) are given for each regional and housing type scenario.

			Time (min)				**Distance (km)**			
Scenario (Facility)	**Region**	**Housing Type (Incident)**	**Mean**	**Median**	**Std. Dev.**	**CoV**	**Mean**	**Median**	**Std. Dev.**	**CoV**
Place of Worship	North	PH	8.4	4.8	9.6	1.1	5.2	2.7	6.3	1.2
		MH	13.8	10.8	11.4	0.8	8.9	7.1	7.4	0.8
	South	PH	7.8	4.8	7.8	1.0	4.9	2.7	5.5	1.1
		MH	11.4	9.0	9.0	0.8	7.5	5.6	6.1	0.8
Schools	North	PH	6.0	4.2	5.9	1.0	3.7	2.3	3.7	1.0
		MH	9.6	8.4	7.2	0.8	6.0	5.3	4.0	0.7
	South	PH	6.6	4.2	7.2	1.1	4.4	2.3	5.0	1.1
		MH	10.8	8.7	8.7	0.8	7.3	5.6	5.9	0.8
CDTS	North	PH	12.6	10.7	8.6	0.7	8.0	6.9	5.7	0.7
		MH	12.3	10.7	8.7	0.7	7.8	6.8	5.6	0.7
	South	PH	31.8	31.2	19.2	0.6	24.7	24.1	15.8	0.6
		MH	33.0	29.4	21.0	0.6	25.4	22.2	16.9	0.7
All Shelters	North	PH	4.10	2.57	4.22	1.0	2.72	1.71	2.80	1.0
		MH	6.63	5.49	4.95	0.8	4.39	3.64	3.28	0.7
	South	PH	4.90	2.68	5.61	1.1	3.25	1.78	3.72	1.0
		MH	8.03	5.85	6.87	0.9	5.33	3.88	4.55	0.9

Table 6. Same as Table 5 but for first responder (i.e., EMS stations and hospitals) locations and housing types.

			Time (min)				Distance (km)			
Scenario (Facility)	**Region**	**Housing Type (Incident)**	**Mean**	**Median**	**Std. Dev.**	**CoV**	**Mean**	**Median**	**Std. Dev.**	**CoV**
EMS	North	PH	6.6	4.7	6.0	0.9	4.0	2.8	3.7	0.9
		MH	9.6	7.8	7.2	0.8	5.9	4.8	4.4	0.7
	South	PH	7.8	5.4	7.2	0.9	4.9	3.2	4.9	1.0
		MH	11.4	9.0	8.4	0.7	7.4	5.8	5.8	0.8
Hospitals	North	PH	17.4	13.8	13.2	0.8	12.2	9.5	9.6	0.8
		MH	25.2	22.8	14.4	0.6	18.2	16.7	10.3	0.6
	South	PH	18.6	13.8	15.0	0.8	12.7	8.8	10.9	0.9
		MH	25.8	23.4	15.0	0.6	18.2	16.7	10.6	0.6
All First Responders	North	PH	5.87	4.13	5.57	0.9	3.89	2.74	3.69	0.9
		MH	8.81	7.18	6.58	0.7	5.84	4.76	4.36	0.7
	South	PH	6.88	4.42	6.94	1.0	4.56	2.93	4.60	1.0
		MH	10.97	8.47	8.76	0.8	7.27	5.62	5.81	0.8

Figures

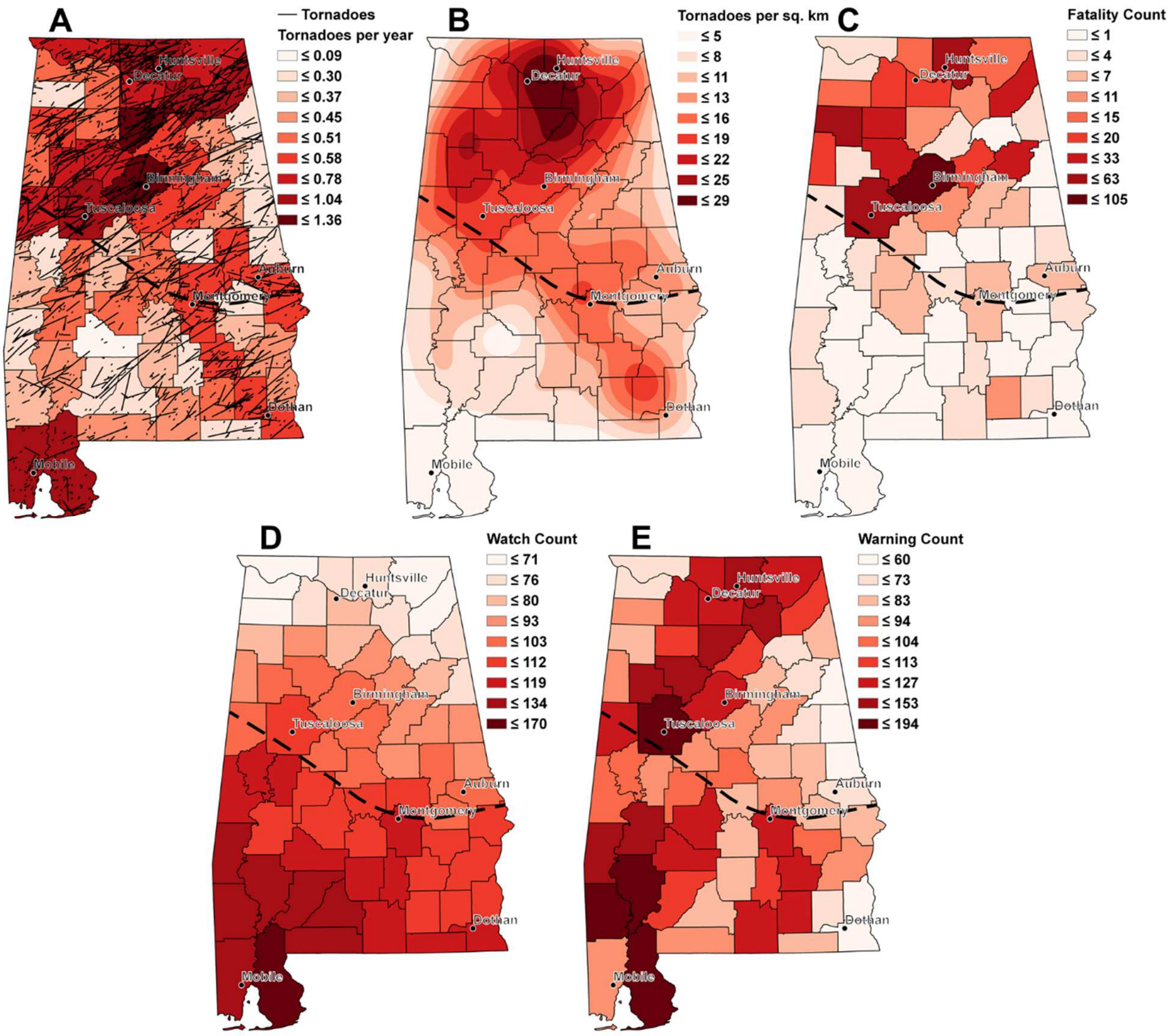

Figure 1. Alabama tornado risk illustrated with A) tornadoes per year (1950-2017), B) tornado density (1950-2017; tornadoes per sq. km), C) fatality counts (1950-2017), D) tornado watch counts (2007-2017), and E) tornado warning counts (2007-2017). The separation from northern and southern Alabama is also depicted by the dashed line.

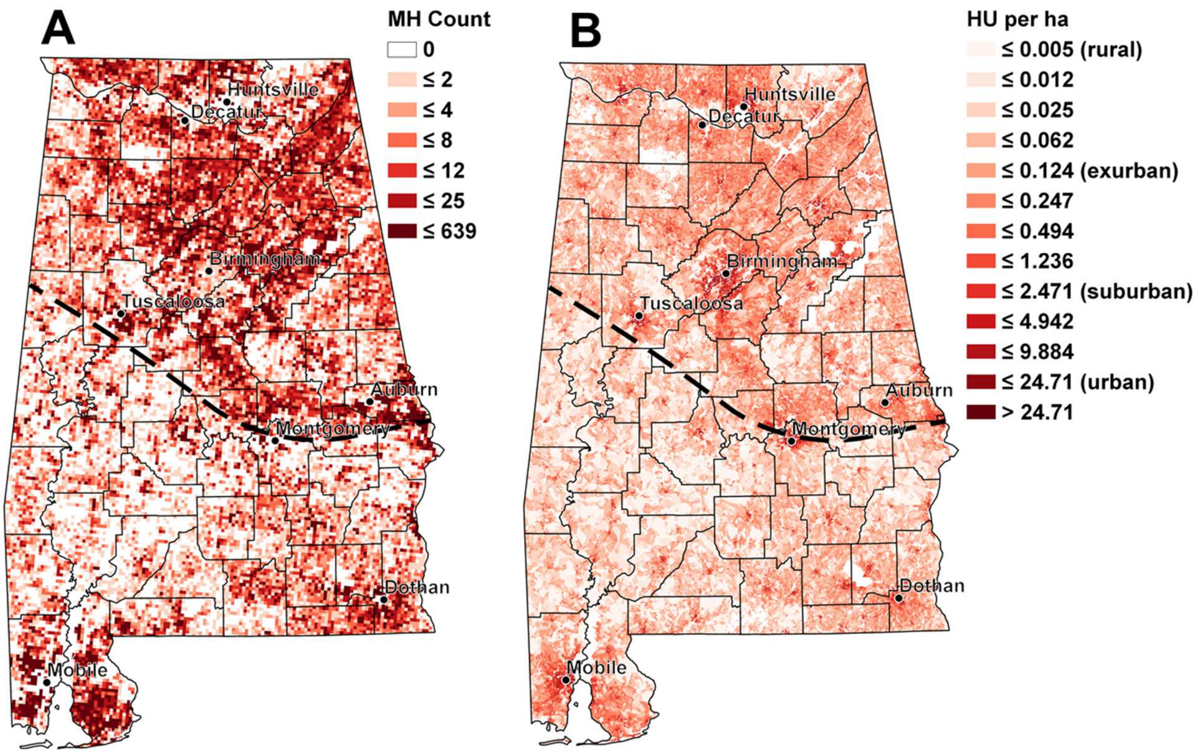

Figure 2. A) Alabama mobile home (MH) counts on a 2-km grid and B) housing unit (HU) density (HUs per hectare). The separation from northern and southern Alabama is also depicted by the dashed line.

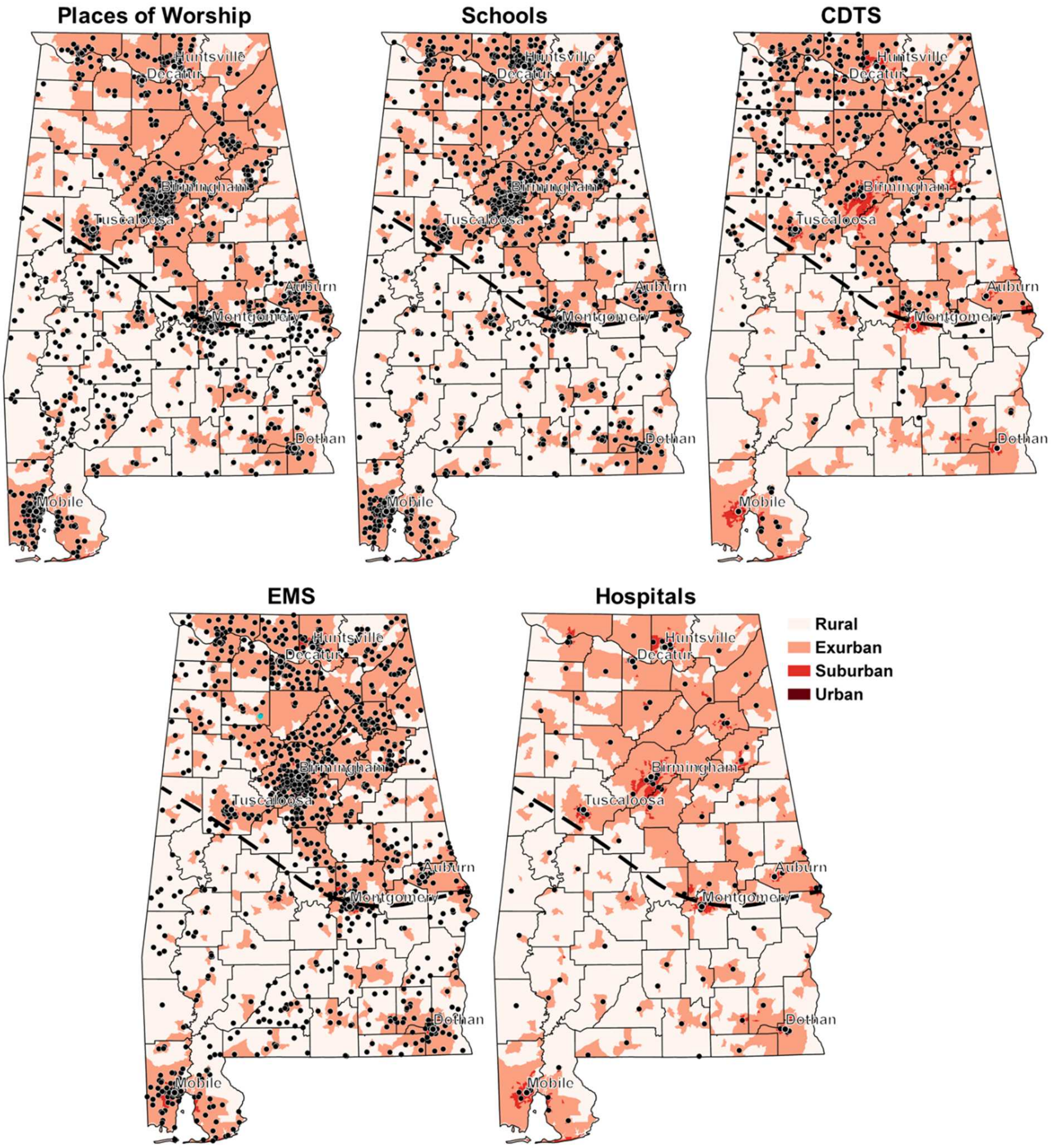

Figure 3. Alabama places of worship, schools, community designated tornado shelters (CDTS), emergency medical services (EMS), and hospital locations overlaid on urban, suburban, exurban, and rural land use density within 2012-2016 American Community Survey (ACS) block groups. The separation from northern and southern Alabama is also depicted by the dashed line.